

terrible thing that can happen to a Nandi is to displease his maternal uncle. Thus it is evident that the Nandi have not long passed from the stage when mother-right obtained.

Mr. Hollis gives an account, illustrated with good figures, of most of the objects made, worn, or used by the Nandi, and a number of folk-tales and riddles

theoretical discoveries, a mass of purely practical results is now available in which the microscope has clearly demonstrated its immediate value.

Perhaps the most fruitful field for the application of the microscope in the present state of our knowledge of metals is the study of the nature and causes of breakages or other failures occurring in practice.

That the thorough clearing up of such cases, wherever possible, is eminently desirable, both in the interests of the parties immediately concerned, and also for the sake of the general advancement of our knowledge, is so obvious that it need not be further insisted upon. It is just where our accepted knowledge and our usual practice go wrong that the field for fresh discoveries lies before us. The methods that are available for the *post-mortem* examination of breakages must depend very much upon the nature of each particular case; experiments that are possible with the broken end of a 12-inch shaft are not applicable to a small brass condenser tube. In every case, however, the first, and perhaps the most vital, step is the examination of the micro-structure of the material close to the actual fracture itself, and also of the mass of the material lying away from the fracture. The first of these sections will often show whether there is any special local weakness in the metal at the point of actual fracture, or whether the fracture itself displays any particular characteristic, for it is well known that the path which a fracture takes among the micro-constituents of a metal depends on both the nature of the metal and the manner in which the fracture was produced. In a given material, for instance, the section of a tensile or bending fracture is quite different from one produced by shock or by repeated alternations of stress. The difficulty about these observations lies, however, in preparing an actual section through the fracture, as this is usually either corroded or worn by subsequent friction; when it is clean and fresh, however, the actual fracture may be embedded in a thick deposit of electrolytic copper, and a satisfactory

section may be cut through the compound mass thus formed. An example of a section of this kind is shown in Fig. 1.

Apart from the examination of the fracture itself, the general micro-structure of the material will, as a rule, reveal whether it has been subjected to any undue treatment during manufacture or use. Thus excessive heating, whether by exposure to an unduly high temperature or to a more moderate temperature for an unduly long time, leaves its trace in the form of a coarse, angular structure which is readily recognised in such materials as steel, brass, or bronze. Insufficient rolling or forging, or working at either too high or too low a temperature, can also be readily diagnosed. In many cases a useful guide can be obtained by comparing the micro-structure of the object which has failed with that of a similar object which has given good service; but this is only necessary where the material in question is one which has not been thoroughly studied, so that the effects of various forms of treatment on the micro-



FIG. 2.—A wife and daughter of Ar-ap-Koilepe, the chief medicine man of the Lumbwa. From "The Nandi."

are given in the original language and in translation. It will thus be seen that Mr. Hollis has made a noteworthy contribution to our knowledge of the ethnology of British East Africa.

A. C. H.

THE MICROSCOPE IN ENGINEERING.

DURING the past ten years the young science of metallography has made rapid strides, and in consequence of this development the microscope is steadily assuming an increasingly important position in the testing-laboratories of those who have to deal with metals, either as manufacturers or users. This position has, however, been accorded to it with some reluctance, partly, perhaps, because at the outset too much was claimed for the instrument. Another cause is to be found in the fact that, as is necessarily the case in all young sciences, theoretical development has outstripped practical application, and practical men are too apt to regard anything "theoretical" as practically useless. But even if we leave aside all questions of the promising future applications of these

structure are not so definitely known as could be desired. Fortunately, the list of such materials is rapidly diminishing, but, owing to the wide range and complexity of industrial alloys, cases of this kind will continue to occur occasionally.

Although the microscopic evidence is, as a rule, quite conclusive, it is eminently desirable to supple-

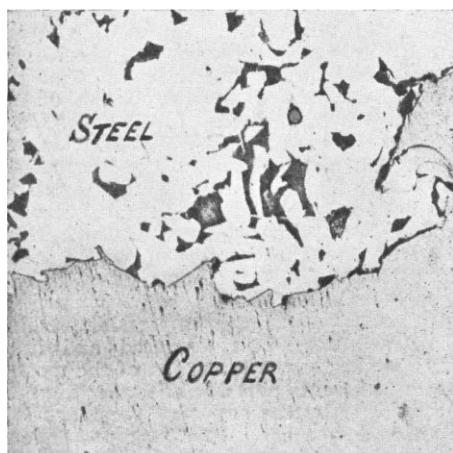


FIG. 1.—Section through a fracture of mild steel, after embedding in an electro-deposit of copper. The path of the fracture among the constituents of the steel can be clearly traced. Magnification, 100 diameters.

ment it wherever possible by the data of a careful chemical analysis and complete mechanical tests, dynamic as well as "static." Even where these additional data are not needed to confirm the conclusions drawn from the microscopic examination, they are valuable as throwing a light upon the indications of the various forms of test relied upon by engineers in drafting their specifications.

This consideration raises the question how far it would be possible or desirable to include an examination of the micro-structure in the regular tests carried out on engineering materials. Some time ago metal manufacturers, and more particularly steel makers, would have met such a proposal with every means of opposition in their power, but greater familiarity with questions of micro-structure has, it may be supposed, diminished this feeling. If it were simply a question of imposing an additional test, or of placing an additional difficulty in the way of the manufacturer who has to comply with specifications, a hostile attitude would, of course, be readily understood, but the effect of the inclusion of microscopic examination in regular testing would not be at all likely to increase the stringency of the specifications in question. Thus, as regards chemical compositions, specifications are so drafted that, even with unfavourable structure, the material may be strong enough to meet the mechanical requirements of the engineer. Were it possible to rely upon obtaining a favourable structure in the material as used, the necessity for stringency in regard to composition would be materially reduced.

Further, the use of the microscope in this connection should enable the engineer to rely more securely upon both the uniformity of his materials and on their conformity with the test specimens. The reason is that, by the microscopic examination of a number of very small pieces chosen from a variety of different pieces or parts of the material, it would be at once ascertained whether the material was uniform, and whether the test-pieces chosen for mechanical testing or for chemical analysis fairly represented the bulk

of the material. This again is an application of the microscope in engineering practice which could not be regarded as operating against the interests of the makers of the material; the rejection of metal on the results of tests carried out on samples which happen to be below the average of the batch would be prevented quite as often as the acceptance of a batch on results obtained from an unduly favourable sample.

In the case of large pieces of metal also, the application of the microscope would prevent the occurrence of failures which sometimes arise as a consequence of want of uniformity in the materials forming different parts of the same forging. Such differences may arise either from segregation, *i.e.* from a non-uniform distribution of the constituents or the impurities in the metal as originally produced, or it may be the result of insufficient or of wrongly applied working. Thus, if rods of ductile metal, such as brass, are drawn down cold too rapidly, or if the reduction at each pass through the dies is incorrectly adjusted, the result is the production of a surface layer of material which has been much more heavily deformed than the core of the rod, and this results in a condition of serious internal stress which may even produce subsequent spontaneous fracture.

In large forgings also, an external layer of fine-grained material is sometimes found superposed on a coarse-grained core as the result of inadequate working. This also is liable to lead to failure in use, while the indications of test-pieces cut from the fine-grained layer are entirely falsified by the real behaviour of the piece as a whole. An example of the diversity of structure to be met with in different parts of the same piece of metal is shown in Fig. 2, the two halves representing, to the same magnification, the structure as seen in the outer and central

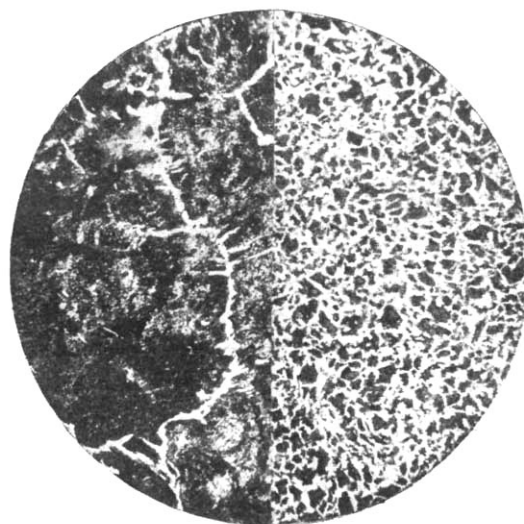


FIG. 2.—Sections from two parts of the same large forging; the right-hand half of the figure represents the fine structure of the external layers, while the left-hand half represents the coarse structure of the interior. The magnification of both is 50 diameters. The dark and light areas in both portions represent pearlite and ferrite respectively.

layers of a large forging. This example is, of course, abnormal, but the intelligent use of the microscope in ordinary testing practice would prevent such a piece from passing into use.

Examples of other uses of the microscope in connection with the materials of engineering could be given in great numbers. Perhaps one of these which

is already most appreciated in practice is the use of the instrument to control the annealing processes in connection with copper and its alloys. The whole history of the constitution and structure of the more important alloys of copper with one added element at a time has been worked out and embodied in what appear at first sight to be highly theoretical "equilibrium diagrams." These diagrams, however, enable us to understand the precise effect produced upon the constitution and structure of any of these alloys by thermal treatment. The structures resulting from exposure to certain temperatures, followed by either slow or rapid cooling, have been determined, as well as the particular properties of the alloys which correspond to these structures. An understanding of these diagrams therefore enables the manufacturer or user to treat his alloys at the proper temperatures, and to control the results with ease and certainty by examining a few specimens of the metal under the microscope and noting the type and the size or scale of the structure.

At the present moment the control of these processes is only satisfactorily available for those groups of alloys the constitution of which has been fully investigated, but this is so far the case only for binary alloys—i.e. those consisting of two metals only. The majority of industrial alloys are much more complex, and for these the theoretical guidance is not yet available, principally because the complete study of these complex systems is a matter of much greater difficulty than that of the simpler binary series. The fullest benefit of the microscope will therefore only become available for workers who deal with these complex alloys when the purely scientific investigations have covered this difficult ground; but meanwhile it is quite possible in practice to obtain empirical data as regards the best micro-structure and the treatment required to obtain it. Such data, although not of equal value with the more complete knowledge, form a useful temporary substitute.

These few indications of the present practical utility of the microscope in connection with engineering materials, while very far from covering the whole range of the subject, may perhaps be enough to show that, even with existing knowledge, the instrument is capable of rendering—and is, in fact, rendering—the greatest service to engineering and metallurgical practice. These fruits are already derived from little more than twenty years of metallographic investigation. For the future of this young science, therefore, the highest hopes appear to be well founded.

WALTER ROSENHAIN.

THE YIELDING OF THE EARTH TO DISTURBING FORCES.¹

THE problem of determining how much the earth as a whole actually yields to the tidal disturbing forces of the sun and moon was definitely brought before scientific men by Lord Kelvin. He pointed out that, from observations of the tides of long period, it ought to be possible to obtain some definite information, and he urged the establishment of gravitational observatories fitted with instruments for detecting the lunar disturbance of gravity. However rigid the body of the earth may be, it necessarily yields a little to the deforming action of the sun and moon. This action produces two kinds of effect. In the first place, it alters the shape of the earth. If the earth were a perfect sphere, it would be drawn

out by the attraction of the moon, for instance, into a prolate ellipsoid of revolution. The actual earth, of a shape that is nearly spherical but presents certain inequalities, acquires under the action of the moon a slight additional inequality of figure, of the same type as that which answers to elongation in the direction of the long axis of the ellipsoid and flattening round the parts remote from that axis. As the moon moves relatively to the earth, the long axis of the ellipsoid moves about in the earth, so that a corporeal tide is raised in the earth. Besides raising a corporeal tide, the action of the moon alters the attraction of the earth. If the change of external shape only is taken into account, the alteration of the attraction consists of the added attraction, due to the protuberances at the ends of the long axis of the ellipsoid, coupled with the loss of attraction, due to the flattening round the parts remote from these ends. But, since the material of which the earth is made up is not homogeneous, a similar effect is produced by the elongation and flattening of the surfaces of equal density, and, since the material is not absolutely incompressible, the density must be in some parts increased and in others diminished, owing to the attraction of the moon being different in different parts. The alteration of the earth's attraction by the action of the moon is therefore of a somewhat complex character. The effects produced by the action of the sun are similar to those produced by the action of the moon.

Many attempts have been made to measure the changes of level that are due to the tidal disturbing forces of the sun and moon. In the majority of such attempts, instruments of the horizontal pendulum type have been used. The displacement of a horizontal pendulum that would be produced by the attraction of the moon, or the sun, if the earth were absolutely rigid, is known, for the attractions of the moon and sun are known. In the actual case, owing to the yielding of the earth, all we can hope to determine by observations of the tides or of the displacement of horizontal pendulums is a relative change of level, and to measure this is far from easy. The effect to be measured is extremely minute, and it is liable to be obscured, or even disguised altogether, by the effects of air currents and of changes of temperature. Recently Dr. O. Hecker, of Potsdam, has succeeded in overcoming the experimental difficulties. By setting up two horizontal pendulums in an underground chamber, and observing their behaviour during a protracted period, he was able to show that the effect of the moon, in particular, is perfectly definite, that in phase it follows very closely the motion of the moon, and that in amount it is almost exactly two-thirds of what it would be if the earth were absolutely rigid.

Hecker's result confirms decisively the results which had been found with much less perfect experimental means by previous observers. It leaves no shadow of doubt of the actuality of a corporeal tide produced by the moon. It accords also with those results, deduced from observations of fortnightly tides, which were used by Lord Kelvin in his famous estimate of the rigidity of the earth. This estimate was obtained by working out mathematically the change of shape that would be produced by the attraction of an external body, such as the moon, in a solid elastic globe, of the same size and mass as the earth, if the material of which it is made were homogeneous and absolutely incompressible. When these simplifying assumptions are made, the change of attraction is calculable in terms of the change of shape, and the measurement of the relative change of level leads easily to the determination of the absolute change of

¹ Based on a paper by Prof. A. E. H. Love, F.R.S., read before the Royal Society on January 14.